THE

JOURNAL OF GEOLOGY

MAY–JUNE, 1901

GLACIAL AND INTERGLACIAL BEDS NEAR TORONTO

AN article on the present subject was published in 1895 in the JOURNAL OF GEOLOGY;[1] but the five years since that time have added so much to the completeness of our knowledge of this important Pleistocene area as to justify a fresh account of the region. At the Toronto meeting of the British Association in 1897 the series of interglacial beds for which Professor Chamberlin had suggested the name "Toronto Formation" aroused so much interest that a committee was appointed for its investigation and grants were made at this and the two following meetings to cover the expense of excavations to solve some problems in connection with the beds. The final report of the committee, prepared by its secretary, the present writer, with a separate report on Pleistocene plants in Canada by Professor Penhallow, was made at Bradford in 1900, summing up the facts and giving lists of the interglacial fauna and flora, thus providing the materials for a more complete discussion of the events recorded in the "drift" of the region than has been attempted before.

The interglacial beds of Scarboro' near Toronto were first studied more than 20 years ago by the well-known English pale-

[1] JOUR. GEOL., Vol. III, No. 6, pp. 622, 645.

ontologist, Dr. George Jennings Hinde,[1] but his excellent work attracted little attention and the importance of the facts brought to light seems to have been overlooked by Pleistocene geologists. In 1894 the Don interglacial beds were described by the present writer,[2] who has since then given careful study to the numerous

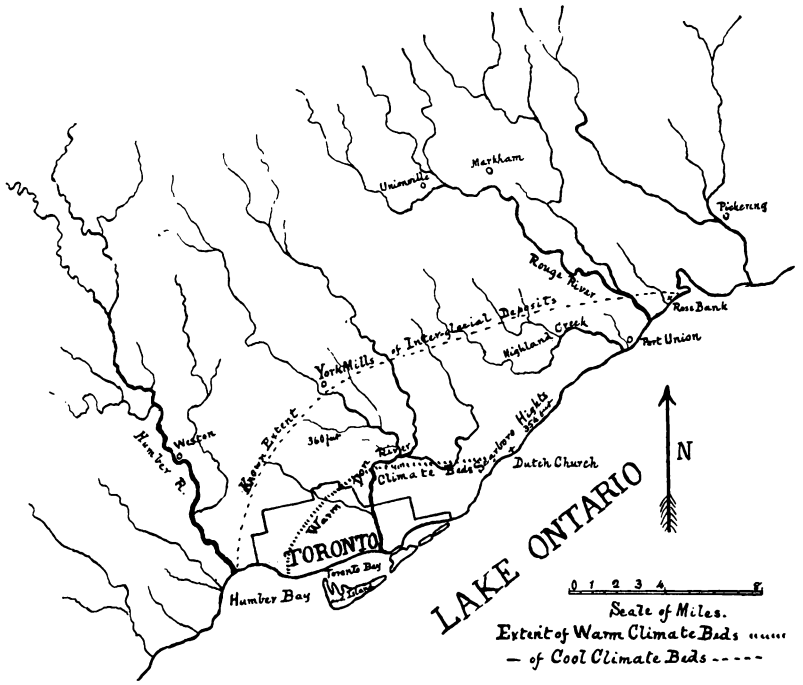

FIG. 1.

and excellent sections presented by Scarboro' Heights, the ravines of the Don, and many excavations carried on in and about the city of Toronto. A large number of fossils have been collected by Mr. J. Townsend and the writer, and Professor Penhallow has determined the plant remains, Dr. Dall and his assistants the shells, and Dr. Scudder the insects. These gentlemen have shown the greatest skill and patience in working up what was often very difficult material, and much of the value of the results of the investigation is due to them, particularly in determining

[1] Canadian Journal, 1878, p. 388 *et seq.* [2] Am. Geol., Vol. XIII, 1894, pp. 85–95.

the important changes of climate indicated. In the following paper an attempt will be made to give a connected history of the events which have occurred in the Ontario basin during the time represented by the Toronto Formation and the sheets of till below and above it, generally held to belong respectively to the Iowan and Wisconsin ice advances.

RETREAT OF THE IOWAN ICE SHEET

The retreat of the Iowan ice was probably accompanied by one or more lakes similar to those whose raised beaches, formed during the retreat of the last ice sheet, are so well marked around the present great lakes. Though no remnants of Iowan beaches are known to exist, there is strong faunal evidence of at least one glacially dammed Iowan lake. When the region was ice covered, all aquatic life must have been destroyed, so that any species occurring in interglacial beds must have migrated into the region from river systems beyond the reach of the ice. The unios which are so striking a feature of the lower beds of the Toronto Formation are Mississippi forms. As there is no more proof of direct connection between the Ontario basin and tributaries of the Mississippi during interglacial times than now, we may suppose that these shellfish entered the basin in a round-about way by means of an interglacial upper lake, draining at first past Chicago into the Mississippi, but afterwards finding an outlet by the Laurentian river into the Ontario valley and thence into the gulf of St. Lawrence.

After the Iowan glacier had retreated so far that lakes dammed by it had been drained, the St. Lawrence system of waters no doubt returned to much the same channels as before the advance of the ice, since there is no evidence that any great thickness of drift had been left to block the way. The lowest till at Toronto is generally thin, running from a foot or more near the bend of the Don at the paper mill to 8 or 9 feet at the Gerrard street bridge. At one point in the west end of the city, however, 35 to 40 feet of till occur, but a well-defined "bowlder pavement," with all the stones at the same level and striated on

their upper surfaces, is found 4 or 5 feet above Lake Ontario, and perhaps indicates that the upper 30 feet are of later age than the Iowan. Farther west along the shore of the lake the till sheet is not more than 10 or 15 feet thick. So far as known, this layer of till is nowhere thick enough to have modified greatly the shape of the surface, which may now be roughly sketched.

The highest point of the Hudson River shale near Toronto is at Weston, 7 miles northwest of the city, where it reaches about 200 feet above Lake Ontario. In the Don valley the shale runs from a little below lake level near the mouth of the river to 30 feet above it 2 or 3 miles to the north; but 5 miles east of the Don a well sunk at the foot of Scarboro' Heights failed to reach the rock at 41 feet below the lake, and beyond this bedrock is not found for a long distance, first appearing at Pickering, 15 miles to the east. This implies a width of about 25 miles for the mouth of the valley occupied by the preglacial (and also interglacial) Laurentian river whose old channel from Georgian Bay to Scarboro' has been indicated by Dr. Spencer.[1] The valley narrowed somewhat rapidly, however, toward the northwest, for on the upper reaches of the River Rouge between Unionville and Markham numerous angular slabs of Hudson River rock, evidently not far from their source, are found more than 300 feet above Ontario. The distance from this point to Weston is 16 miles in a southwesterly direction, and between the two points, the ravines of the Don and wells which have been sunk prove that a channel of considerable depth existed.

[1] Duration of Niagara Falls and History of the Great Lakes, pp. 18 and 19.

Dr. Spencer's idea of a present channel 474 feet deep, running from Scarboro' Heights across Ontario to the deep water near the south shore seems founded on an erroneous sounding as marked on Bayfield's chart. A series of soundings carried out by the present writer in 1898 across the supposed deep channel showed no such interruption in the gentle southward slope of the bottom, the depth at about the position of the 474 feet sounding on the chart being 175 feet. Probably the 4 is in mistake for 1, and the true sounding was 174 feet. The old channel across Lake Ontario was filled in completely, so far as one can ascertain, by stratified clay and till in later times and so has long ago disappeared. The fact that Scarboro' Heights, rising 375 feet above the lake, have been piled up since then may be considered sufficient proof of this.

We may suppose then that the great preglacial valley, though coated with a sheet of bowlder clay by the Iowan ice, had probably much the same form and dimensions at the end of that ice invasion as before. If there was an interglacial episode similar to the postglacial lake Iroquois no certain remains of its beach deposits are known, and the level of the water when the laying down of the Toronto Formation began was not greater than that of Lake Ontario and may have been considerably beneath it; for the lowest unio beds lie more than 40 feet beneath the present lake at Scarboro'.

Before the formation of similar beds at higher levels considerable erosion took place, as at the bend of the Don where these deposits occupy an old river channel cut through the Iowan till into the Hudson River shale to the depth of at least 16 feet, as shown by a cutting of the Don, at this point 19 feet above Ontario. The bowlder clay has been cut through to the shale in the western part of Toronto also, as shown in a well bored for purposes of exploration, the bottom of the interglacial deposits being 17 feet above Lake Ontario. It seems clear that rivers had been at work for some time before the unio beds were formed.

WARM CLIMATE BEDS OF THE DON VALLEY

The earliest beds of the Toronto Formation were deposited on the eroded surface of the Iowan till or on the shales which had been laid bare beneath it by river action; and they were formed probably in the shallow waters of a lake, though some features suggest the action of currents. At the bend of the Don, coarse, little rounded shingle of the harder layers of the underlying Hudson River rocks makes the lowest bed visible above the present river, and suggests the action of a current rather than of waves. Thick sheets of vegetable matter, greatly decayed twigs, leaves, reeds, etc., with trunks and branches of trees are interbedded with the shingle, however, showing that the current could not have been swift. Possibly these beds were formed just at the mouth of a small river like the present Don, where it entered a lake standing 20 or 30

feet higher than Ontario. If this is correct there had already been a damming back of the interglacial waters to a higher level than has been reached yet in postglacial times. This damming could not have been by ice, for the climate was at least as mild as at present, since the tree trunks referred to include wood of the red cedar, an elm, the pawpaw and three species of oak; and among the shellfish there are two not reported from Canadian waters at the present day, though found in the Mississippi, Quadrula (unio) pyramidata and Anodonta grandis.[1]

As the beds at Taylor's brickyard, which have been described in former papers, have been traced as far east as the bend of the Don at the edge of the interglacial valley just referred to and also as a thin lower layer across these deposits, we may include the whole in one section, commencing with the bend of the Don as a basal series and running up through the series at the brickyard as far as the cold climate stratified clays.

SECTION AT TAYLOR'S BRICKYARD

		Feet
8.	Yellow or brown sand with some reddish clay (no fossils)	3–60½
7.	Blue peaty clay with some gray sand (unios, wood, caribou horn)	4½–57½
6.	Yellow to brown sand with thin layers of purplish clay (shells)	14–53
5.	Fine gray and yellow sand (unios and other shells)	3–39
4.	Blue stratified clay and sand (unios with other shells and logs of wood), above 2½ feet of bowlder clay resting on Hudson River shale	2–36

SECTION AT BEND OF DON

3.	Brown clay with sandy layers (unios, campeloma, etc.)	5–34
2.	Blue clay with sandy layers (unios, anodons, wood)	6–29
1.	Coarse shingle with clay and peaty layers (shells and logs)	4–23
	River Don above Lake Ontario	19–19

From the combined section given above it will be seen that the warm climate beds of the Don commencing 19 feet above Lake Ontario have a total thickness of 41½ feet. It should be

[1] Notes on Can. Unionidae, J. F. WHITEAVES, Can. Rec. Science, 1895, No. 5, p. 250; and No. 6, p. 365.

added however that no fossils have been obtained from the uppermost three feet of brown sand. The lower section differs slightly in fauna from the upper one, containing numerous anodons and campelomas, which are almost absent from the beds at the brickyard; but the unios and trees are alike.

In previous papers the warm climate beds have been represented as ending just beneath the peaty blue clay (No. 7) which was considered to belong to the cool climate beds, chiefly because it contained peaty layers and had yielded a shed horn of caribou. Recently, however, the peat has been examined and found to contain no mica scales and very few mosses or spruce needles, which are very characteristic of the peaty layers belonging to clays of the cool climate. Instead of this the brown layers consist mainly of fragments of deciduous leaves. The recent finding of unios at the top of the blue clay strengthens the opinion that it and the brown sand above should be included with the warm climate beds. The lowest point at which the unio clays and sands have been found is 41 feet below Lake Ontario at the foot of Scarboro' Heights, giving a vertical range of more than 100 feet for the whole series of warm climate beds The following species have been obtained in the Don beds:

FAUNA OF WARM CLIMATE BEDS, DON VALLEY

Vertebrata: possibly mammoth or mastodon and bison, and an undetermined fish.

Arthropoda: several undetermined beetles and cyprids.

Mollusca:

Unio undulatus	still living in Lake Ontario.
" rectus	
" luteolus	
" gibbosus	
" phaseolus	still living in Lake Erie, but not reported from Lake Ontario.
" pustulosus	
" trigonus	
" coccineus	
" occidens	not known in the St. Lawrence system of waters, but living farther south.
" solidus	
" clavus	
" pyramidata	

Anodonta grandis, not reported from Canada.
Sphaerium rhomboideum
" striatinum
" sulcatum
" solidulum
" similis (?)
Pisidium Adamsi
" compressum
" novaboracense (?)
Pleurocera subulare
" elevatum
" Lewisi (?)
Goniobasis depygis
" Haldemani
Limnaea decidiosa
" elodes
Planorbis parvus
" bicarinatus
Amnicola limosa
" porata
" sagana
Physa heterostropha
" ancillaria
Succinea avara
Bythinella obtusa
Somatogyrus isogonus
Valvata sincera
" tricarinata
Campeloma decisa
Bifidaria armata (land snail)

In all there are thirty-nine undoubted species of mollusks, and three more probably, included in the fauna. Of these eight or ten have not been reported from Lake Ontario, but occur farther south.

FLORA OF WARM CLIMATE BEDS, DON VALLEY

Acer pleistocenicum
" spicatum
Asimina triloba
Carya alba
Chamaecyparis sphaeroidea
Crataegus punctata
Cyperaceae sp.
Eriocaulon sp.
Fraxinus quadrangulata
" sambucifolia
" americana
Festuca ovina
Hypnum sp.
Juniperus virginiana
Larix americana
Maclura aurantiaca
Picea nigra
" sp.
Pinus strobus
Platanus occidentalis
Populus balsamifera
" grandidentata
Prunus sp.
Quercus obtusiloba
" alba (?)
" rubra
" tinctoria
" oblongifolia
" macrocarpa
" acuminata
Robinia pseudacacia
Salix sp.
Taxus canadensis
Thuya occidentalis
Tilia americana
Ulmus americana
" racemosa
Vaccinium uliginosum

Professor Penhallow, from whose report to the British Association in 1900 this list is taken, states that "within this area no less than thirty-eight species have been recovered, and they point conclusively to the existence of climatic conditions differing materially from those which now prevail, and of a character more nearly allied to those of the middle United States of today." "Only one species appears to have disappeared in Pleistocene time. Acer pleistocenicum, which was abundant in the region of the Don, bears no well defined resemblance to existing species."

The plant remains consist chiefly of wood and leaves, the former usually much flattened from the pressure of the later ice sheet, but otherwise often well preserved, the red cedar, for instance, showing its color and being still quite tough, although some of the wood, probably decayed before being waterlogged and included in the clay, is in a worse condition. Parts of the wood are almost of the nature of brown coal breaking across easily and showing a coaly luster on the broken surfaces. It may be worthy of mention that some large bits of porous charcoal, as if from the burning of a log, were found cemented with limonite in the sand (No. 6) just under the blue clay. The leaves are preserved generally in the thinner beds of clay and are rarely obtained whole.

The sands of the Don beds vary greatly in fineness and color, and are more or less cross bedded and mixed with gravel, as if deposited under wave action; while the coarse shingle at the base of the section near the bend of the Don looks like the work of a river. The upper part of the warm climate beds of the Don, consisting of stratified clay (No. 7) and sand (No. 8) appears to have been formed under distinctly lacustrine conditions. At the beginning of the formation there may have been no lake, only a great river with a tributary or tributaries coming in from the west; but at its close there was a great lake which stood at least sixty feet above Lake Ontario at present. Whether the change in water levels was slow or rapid there is no evidence to show. That the water remained for some time

at the higher level is testified by the thorough oxidation of the iron in the upper sandy beds, which are in some layers deep brown in color, and completely cemented with limonite. The blue layers (2, 4 and 7) have retained their color because of the large amount of deoxidizing vegetable material present in them.

The change in the level of the interglacial lake effected a great change in another respect. Where the valley of the Laurentian river had existed there was now a broad and deep bay running to the north, and the great river began to spread out clay and silt derived from its upper reaches in this basin. The upper bed of blue clay may have been formed by a shifting of the current of the main river, which, however, shifted again while the highest layer of sand was formed, bringing to a close the beds belonging to the warm climate series.

The extent of the Don beds, as indicated by the typical unio sands and clays, is not known very thoroughly, owing to the depth at which they are buried in most places. They occur a few feet below Lake Ontario at Scarboro', four miles southwest of Taylor's brickyard and at Price's brickyard about half way between; and unios have been found in sandy beds of interglacial age at Adare's sand pit on Shaw street, about three miles west of Taylor's. As logs of wood have been found by well diggers at points between, there is a strong probability that the Don beds continue to that point, in which case they have a known extent from east to west of more than six miles, with a breadth from north to south of more than two miles. The real area is probably much greater than this.

THE SCARBORO' OR COOL CLIMATE BEDS

After the close of the Don period the interglacial lake deepened greatly, finally standing more than 150 feet above Lake Ontario, and a great series of clays and sands were deposited by the Laurentian river in the form of delta materials in the wide and deep bay, at this time extending still farther to the north than before. As seen at Taylor's brickyard, the clay beds, gray and finely

laminated, with a few thin peaty layers, rest conformably on the brown sand at the top of the Don beds. The thickness, however, is not great, on account of later interglacial erosion, at the

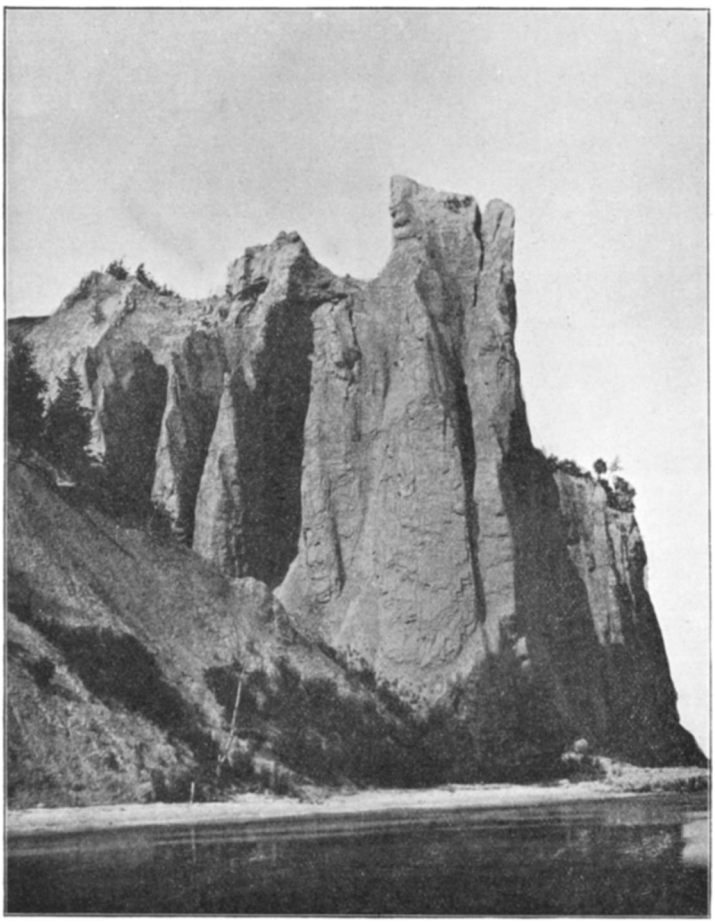

FIG. 2.—Pleistocene Cliffs of Scarboro' Heights.

south end of the clay pit only 7½ feet, 70 yards north, 13 feet, and a quarter of a mile to the northeast 30 feet. These clays are magnificently shown at Scarboro' heights, where they were carefully studied by Dr. Hinde. They commence, as shown in a

well sunk on the shore beneath the cliff, about five feet below Lake Ontario and rise 85 or 90 feet above it.[1] The upper surface mingles somewhat with the overlying sand and varies in height to some extent. The clay is gray, very firm and resistant, almost as much so as the Hudson River shale of the region, and is generally finely laminated, though there are beds from two to four or five feet thick, showing little or no lamination. Besides the fine lamination there are often thin layers of grayish silt with peaty material at distances of one or two inches apart, perhaps representing flood seasons of an annual character. These silty layers cannot often be traced for more than a few feet horizontally, and may run up or down into a bed showing no lamination in a way suggesting cross bedding. Another very characteristic feature is the presence of half inch sheets of greenish impure siderite every two or three feet, though these are not found everywhere.

The silty layers with peaty substances when washed to remove clay and then dried and looked over with a lens show great uniformity in all parts of the region. Scales of mica are always numerous, as well as mosses, spruce leaves, certain round black seeds and chitinous portions of beetles. So constant is this assemblage that these clays are easily recognized by it when found in new localities, the clay ironstone sheets affording an additional earmark. Finally these are the only clays in the region which burn to a dark red brick. As their materials must have been derived by the Laurentian river and its tributaries from the calcareous bowlder clay of the valley to the north, much of the lime must have gone into solution by superficial weathering before reaching the river or have been dissolved during the time of transport, thus allowing the red color due to iron to appear on burning.

From the peaty layers of the clay the beetles were obtained whose names are given in the following lists :

[1] B. A. A. Sc. Rept., Com. on Pleistocene of Canada, p. 3.

Carabidae (9 gen., 34 sp.)

Elaphrus irregularis
Loricera glacialis
" lutosa
" exita
Nebria abstracta
Bembidium glaciatum
" Haywardi
" vestigium
" vanum
" praeteritum
" expletum
" damnosum
Patrobus gelatus
" decessus
" frigidus
Pterostichus abrogatus
" destitutus
" fractus
" destructus
" gelidus
" depletus
Badister antecursor
Platynus casus
" Hindei
" Halli
" dissipatus
" desuetus
" Harttii
" delapidatus
" exterminatus
" interglacialis
" interitus
" longaevus
Harpalus conditus

Dytiscidae (3 gen., 8 sp.)

Coelambus derelictus
" cribrarius
" infernalis
" disjectus
Hydroporus inanimatus
" inundatus
Hydroporus sectus
Agabus perditus

Gyrinidae (1 sp.).

Gyrinus confinis LeC.

Hydrophilidae (1. sp.).

Cymbiodyta exstincta

Staphylinidae (11 gen. 19 sp.).

Gymnusa absens
Quedius deperditus
Philonthus claudus
Cryptobium detectum
" cinctum
Lathrobium interglaciale
" antiquatum
" debilitatum
" exesum
" inhibitum
" frustum
Oxyporus stiriacus
Bledius glaciatus
Geodromicus stiricidii
Acidota crenata, Fabr. (*var.* nigra)
Arpedium stillicidii
Olophrum celatum
" arcanum
" dejectum

Chrysomelidae (1 gen. 2 sp.).

Donacia stiria
" pompatica

Curculionidae (4 gen. 6 sp.).

Erycus consumptus
Anthonomus eversus
" fossilis
" lapsus
Orchestes avus
Centrinus disjunctus

Scolytidae (1 sp.).

Phloeosinus squalidens

Dr. S. H. Scudder, who determined the beetles, thinks that all but two of the 72 are extinct. Twenty-five of the number were named a few years ago from Scarboro' material sent by Dr. Hinde, the rest more recently from specimens collected at various outcrops of the peaty clay by the writer. A complete account of the new species, with figures, will be published shortly by the Canadian geological survey. The number of species of beetles could no doubt be extended if the work of determining them were not so very laborious. In addition to the beetles cyprids occur and rarely also fragments of sphaeriums.

The plants include several trees, Professor Penhallow having found Larix americana, Picea alba and another species of Picea in materials from Price's and Simpson's brickyards; while Dr. Macoun found leaves apparently of willow and alder in peaty material from Scarboro', as well as two shrubs, Oxycoccus palustris and Vaccinium uliginosum, and some smaller plants, such as equisetum, Carex aquatilis and C. utriculata. Dr. Hinde reports five species of mosses belonging to the genera Bryum, Hypnum and Fontinalis; and Mrs. E. G. Britton adds Limnobium. Three species of diatoms, a chara and spores of lycopodium have been reported also.

Dr. Scudder judges from the relationships of the beetles to modern forms that the climate had "a boreal aspect, though by no means so decidedly boreal as one would anticipate under the circumstances." The same conclusion is reached by Dr. Macoun and by Professor Penhallow from the plant remains.

The change from the warm climate fauna and flora to the cool climate ones appears rather sudden, but may not be so in reality. The upper blue clay (No. 7) at Taylor's brickyard has yielded a caribou horn, which suggests a cooler climate than that of the trees and unios a few feet below, since no caribou are known within 150 or 200 miles to the north of Toronto at present. However, the range of the caribou toward the south may have been greater before the white man's settlements encroached on the region. On the other hand the materials of the delta deposits must have been derived largely from the regions to the north

and from a higher elevation, where at present some trees found in the Don valley are wanting, such as Platanus occidentalis, which reaches its northern limit at Toronto.

The peaty clay occupies the western part of the great bay into which the Laurentian river emptied when the interglacial lake was at its greatest height. It appears first at Rosebank, 16 miles east of the Don, and is last seen with certainty 2½ miles west of the river in a sewer on Bathurst street, making a width of 18½ miles. Dr. Hinde reports it also from the mouth of the Humber, 6 or 7 miles west of the Don, but the writer has not been able to find it there, though somewhat loesslike sandy silt containing a few plant remains, occurring near the Humber, may represent the peaty clay of Scarboro'. If so, the whole extent of the beds will be 25 miles from east to west. The last exposure known towards the north is 6½ miles inland from Lake Ontario, and no doubt if the cuttings of the Don were deep enough it would be found considerably farther north. The greatest thickness of the clay at Scarboro' is about 94 feet, 5 below the lake and 89 above; but the upper limit is rather hard to fix, since it becomes interbedded with sand. Toward the west the peaty clay rises higher, reaching 150 feet north of Reservoir Park and in the Bathurst street sewer.

INTERGLACIAL SANDS

Above the peaty clay at Scarboro' there are stratified sands with a thickness of 55 or 60 feet where best developed near the central part of the heights, following the lower beds conformably and apparently laid down in shallower water but under similar climatic conditions. The lower 4 or 5 feet have clayey layers, but above this the sand is quite coarse, through free from pebbles, and shows cross bedding in some layers. In the sand are found all the usual minerals of Archean rocks, and a few bands of garnet and magnetite occur, evidently arranged under wave action, as on the present beach at the foot of the cliff. Just over the peaty clay there is sometimes an accumulation of coarse woody material, flattened twigs, bits of bark, etc., with quite large

branches of Larix americana and Abies balsamea; and similar layers but in less quantity occur at a few points 20 or 30 feet higher up in cross bedded sand. Near the top of the sand numerous nut-like concretions of brown iron ore are found and occasionally also a few shells, such as Sphaerium rhomboideum, S. fabale, Limnaea sp., Planorbis sp., and Valvata tricarinata, but unios have not been obtained from them. The stratified sands were apparently laid down like the clays, from materials brought from the north by the Laurentian river, but in shallower water where wave action was effective, forming wide sand flats and largely filling the western side of the bay previously described. If they stretched eastwards toward the Pickering shore of the bay they must have been eroded afterwards, since they run out 8 or 9 miles from the river Don. That the stratified sand has undergone great erosion will be shown later. The sand is exposed for about 5 miles along the Scarboro' cliffs and is found overlying the peaty clay 6 miles west near Mt. Pleasant cemetery, so that it extends at least 11 miles.

A series of interglacial sands and gravels occurs in western Toronto and is well exposed in large pits near Christie and Shaw streets; but its exact relationship to the Scarboro' deposits is not certain. Where the two series meet near the corner of Dupont and Bathurst streets there are two or three beds of clay with peaty layers interstratified with sand, suggesting that the sand and gravel are of the same age as the Scarboro' clay. In the sewer opened at this point the only fossils found, beyond the remains of beetles, mosses, seeds, etc., from the peaty layers, are a few small bits of wood, which have not been determined, and the ulna of a mammoth or mastodon. The latter, however, may not belong to these beds, since it has been smoothed and scratched by glacial action, and may have lain on the surface at the time of the Wisconsin ice advance.

In the sand and gravel pits half a mile to the west no clay is to be seen and it is not certain whether the beds correspond to the warm climate period of the Don, or to the cool climate period of Scarboro', or include the equivalents of both periods.

At Mr. Adare's sand pit a considerable number of fossils have been obtained, including numerous campelomas, two or three species of pleurocera, Valvata sincera, two or more species of sphaerium, and fragments of unios, all shells which occur in the Don beds. Beside these fossils bits of elephant tusks and a large atlas vertebra, probably of Bison americanus occur, but none of the species is decisive as to climate, though the mammoth or mastodon suggests a cool climate.

The sand and gravel beds have a thickness of at least 78 feet and rise 130 or 140 feet above Lake Ontario, but their extent is unknown, as they are in general buried under bowlder clay. It is certain that these beds were formed under different conditions from those either of the Don or Scarboro'. They are of coarser and more variable materials, often showing very marked cross bedding, probably produced by currents rather than waves, and sometimes apparent unconformities such as are made by a stream changing its bed. We may suppose that an interglacial Humber river coming in from the west or north-west brought down sand and gravel at the edge of the great bay, mingling them at some points with the clayey delta materials of the Laurentian river.

This brings to a close the series of deposits composing the Toronto Formation. In all there are four varieties, the sands and clays of the Don with their warm climate trees and Mississippi unios; the peaty clays of Scarboro' with their seventy extinct beetles and their small flora, suggesting a cool, but not arctic climate; the stratified sands overlying them, probably forming a continuation of the cool climate period; and the western sands and gravels with elephants, bisons and some shellfish affording little evidence as to climate. The maximum thickness observed in each set of deposits is as follows:

3. Scarboro' sands - -	60 feet.	
2. Scarboro' peaty clays	94 "	4. Western sands and gravels, 78 ft.
1. Don beds - -	41½ "	
	195½	

The greatest thickness measured at one place is at Scarboro'

Heights where 150 feet of cool climate beds overlie 36 feet of warm climate beds, making 186 feet in all. However as the 36 feet of unio sands and clays commence 5 feet below the level of Ontario and its water filled the well sunk there before the bowlder clay was reached, it is certain that the Scarboro' section contains more than 186 feet of interglacial beds, but how much more cannot be told. It is probable also that the upper sands once reached higher than at present, since their surface evidently underwent great erosion before the overlying bowlder clay covered them.

DRAINING OF THE SCARBORO' LAKE

At its highest point the great interglacial lake must have stood more than 150 feet above Ontario, since the upper beds of the cold climate deposits reach 152 feet. Then came a fall in the level, whether sudden or slow is uncertain, though a slow drainage seems more probable. The cause of the original rise of the water was probably the elevation of the lower part of the Laurentian river valley, near the Thousand Islands. If so we may suppose that the rise of the northeastern portion of the continent was slow, as it is at present ; and it may not have gone on at a uniform rate, for there seems to have been a halt at 60 feet above the present lake. If the rise was slow the sinking of the barrier at the Thousand Islands at the close of interglacial times was probably equally deliberate. Ultimately the water fell below the present level of Ontario, as shown by the erosion of interglacial valleys in the strata of the Toronto Formation; but whether the lake was completely drained so as to restore the open valley with its great river or was only partially drained is uncertain.

With the lowering of the lake the channels of the rivers must have been rearranged, for the old bay was now largely filled with clay and sand ; and in the Scarboro' section there is evidence of the cutting of three valleys through the stratified sand and peaty clay. The one to the east, where the River Rouge and Highland Creek now flow, was cut down below the

present level of lake Ontario for about five miles, probably by the Laurentian river, which seems to have shifted its bed towards the east as the lake level sank, to avoid the thickest part of the previously formed delta. As no peaty clay has been found in the cuttings made by the Rouge and Highland Creek, but only bowlder clay and later stratified clay and sand, this interglacial valley seems to have been extensive.

Walking westward from Highland Creek the slope of the old valley is seen to rise gently, first the peaty clay showing above the water and becoming thicker and thicker, and then the overlying sand showing itself, finally reaching its maximum thickness about four miles from the first appearance of the peaty clay on the lake shore. How much of the valley already existed before the river began its work is unknown, but at least a considerable thickness of the tough peaty clay must have been cut through, for at Rosebank to the east of the old valley it rises 20 or 30 feet above the lake.

Continuing westward along the shore a second much narrower valley still buried under till and unfossiliferous stratified clay is seen at the "Dutch church," as a vertical promontory three miles from the western end of the Scarboro' section has been called. This "fossil" valley was cut through the full thickness of interglacial sand and clay to a level below the present lake, on the shore of which it shows a width of about 1200 feet. At the top of the peaty clay, 90 feet above the lake, its width is about double this; and its sides then slope gently up to the top of the stratified sand with a total width not much short of a mile. The Dutch church valley was apparently made by a comparatively small stream.

It should be mentioned, however, that Professor Albrecht Penck gives another explanation of the downward dip of the bowlder clay at this point, supposing that the promontory is really a mass of till lodged to the south of an old lake cliff of interglacial times. The old cliff has been exposed again on each side of the Dutch church by the action of the present lake, but the tough clay at that point has resisted better and still remains.

According to this view, after the Scarboro' beds were deposited the water sank to a level below that of the present lake and remained there long enough to cut back the mass of delta deposits to about the position of the present cliff. Although the first explanation seems the more simple, the one given by Professor Penck deserves careful consideration. At present there is not evidence enough to settle positively which is correct.

Toward the west of the Scarboro' exposure the stratified sand gradually thins and disappears beneath the bowlder clay and the same is afterwards true of the peaty clay, which sinks below the lake at Victoria park at the east end of Toronto. Here probably another wide valley was cut, though its western shore is not seen distinctly. The upper stretch of the Don Valley, which turns to the east after emptying into Toronto Bay, discloses only till and the overlying unfossiliferous beds in its ravines, though peaty clay rises to 152 feet near Mount Pleasant cemetery toward the west, and to nearly 100 feet at Price's brickyard to the southeast, suggesting an old river valley between, perhaps of an interglacial Don. The form of this valley is not so well worked out, however, as in the case of the other two.

As no interglacial deposits have been found clearly belonging to this later low water stage, there is no evidence as to the climate during the latter part of the interglacial time; but we may suppose that it grew colder until the region was once more covered with an ice sheet, probably corresponding to the Wisconsin till of the states to the southwest.

LATER GLACIAL DEPOSITS

The earlier (Iowan) ice advance found little obstruction in the region of Toronto and passed over leaving only a comparatively thin sheet of bowlder clay, not greatly modifying the general form of the surface; but the later glacial invasion took place under changed conditions. The broad Georgian Bay — Scarboro' Valley through which the Laurentian river had flowed, was now largely blocked with the great interglacial delta deposits, which no doubt stretched as a tongue some miles in length

out into the valley of the present Lake Ontario. The lower part of these deposits consists of very firm stratified clay strengthened by sheets of clay ironstone; but at the eastern end of Scarboro' Heights the clays have been greatly crumpled and contorted, and even large blocks shifted and tilted, by the pressure of the on-coming Wisconsin ice. As the delta seems to have run about southeasterly it lay almost directly athwart the course of the advancing ice, which, after crossing the later valley of the Laurentian river, had to climb over a ridge at least 150 feet in height, and probably considerably higher, before proceeding on its way diagonally across the Ontario Valley. This obstruction, perhaps aided by climatic variations, seems to have kept the ice more or less in check. Meantime the lower end of the Ontario Valley must have been blocked with ice so that the water once more rose assorting the "rock flour" furnished by subglacial streams as gray stratified clays without fossils overlying the uneven surface of bowlder clay covering the series of ridges and valleys left by the interglacial rivers.

The halt at the Scarboro' delta was long and must have included at least three great oscillations of retreat and advance to account for the complex of tills separated by stratified materials now crowning the heights. The first sheet of till is shown for about nine miles continuously at Scarboro' with the shape of a slightly bent bow, touching the lake at each end and with a sharp downward dip at the Dutch church. The latter is, however, less symmetrically placed than in a bow, being only three miles from the west end and six from the east.[1] The hollow of the Dutch church valley was filled with till containing comparatively few stones to a level 50 or 60 feet above the present lake, then merging into gray stratified clay which rises to a height of 165 feet, where it is covered with a few feet of much later Iroquois beach gravel. Very similar clays rising to the same height or a little higher are found at brickyards to the north of Toronto. They burn to a gray brick and so are

[1] See diagram, JOUR. GEOL., Vol. III, No. 6, 1895, p. 624.

easily distinguished from the peaty clay which makes red brick.

The highest part of the Scarboro' escarpment, about a mile east of the Dutch church, gives the best section of these complex glacial deposits. At the point where the old Iroquois beach is cut off for a distance by the present lake cliff, there is a face of 270 feet displaying three layers of bowlder clay separated by stratified sand, the whole overlying the stratified fossiliferous sands of the Toronto Formation. A few hundred yards to the east of this the escarpment reaches its highest level, 354 feet above the lake, but the lower part is not so well shown. The upper portion is, however, more complete, since overlying the third till sheet one finds laminated grayish blue or purplish clay followed by evenly bedded fine sand, on which rests a fourth bowlder clay. Putting the two sections together we have the following complete section:

	Feet	
Bowlder clay No. 4	48–354	
Stratified sand overlying stratified clay	36–306	
Bowlder clay No. 2	32–270	
Silty sand, the upper layers crumpled	25–238	203 feet Glacial Complex
Bowlder Clay No. 3	9–213	
Cross bedded sand	29–204	
Bowlder clay No, 1	24–175	
Fossiliferous sand	59–151	
Peaty clay	92– 92	151 feet, Toronto Formation
Lake Ontario	0	

The whole series of tills with the interstratified sand and clay at Scarboro' amounts to 203 feet in thickness and implies a glacially dammed lake reaching more than 300 feet above Ontario. The highest stratified materials in the neighborhood of Toronto occur, however, at the North Toronto waterworks, 360 feet above the lake, where a well showed several beds of clay alternating with sand and gravel, probably equivalent to some of the beds at Scarboro'.

No fossils have been found in the sands or clays of the glacial complex at Scarboro', but a few have been picked up in stratified sand lying between two beds of bowlder clay at the

Metropolitan power house, a mile or two north of Toronto, Amnicola limosa, a Succinea and fragments of another species. These occur at 220 feet above the lake, but the sand containing them runs up to 247 feet and may correspond to the silty sand between till No. 2 and till No. 3 at Scarboro'.

One of the recessions of the ice, perhaps the one just mentioned, appears to have been very extensive, for two thick beds of bowlder clay are found to be separated by stratified materials at numerous points on the lake shore as far east as Newtonville, fifty miles from Toronto. The same relationship is found near the headwaters of the Don, about eight miles north of the city, and also in ravines to the east, but has not been observed to the immediate west; though the stratified clays lying between two layers of till at Dundas and at several points near Niagara Falls may correspond to the same interglacial stage. In that case the ice must have withdrawn eighty miles in a northeasterly direction before advancing again.

During the first recession of the ice the lake was dammed to a level at least 160 feet above the present, for roughly stratified grayish clay with a few small polished and striated stones is found at many points at about this level, filling in hollows of the bowlder clay, as at the Dutch church and Taylor's brickyard. Afterwards, as shown above, the water stood much higher, since stratified materials are found 360 feet above Ontario or 606 feet above the sea, and may have formed part of a large body of water, covering Lake Erie as well as the western end of Ontario. As the whole of these stratified clays and sands were afterwards overridden by the ice and covered with the latest sheet of till they must be looked on as interglacial. The highest bowlder clay has not yet been traced with certainty west or south of the Toronto region, however, since the four sheets of bowlder clay are very much alike and cannot be discriminated when found alone; and there is a possibility that it ends here, and that the water then filling the Ontario basin was continuous with that of some of the successors of Lake Warren. If so, beach lines may have been formed to the west or south of Lake Ontario while

the last till was being spread over the upper interglacial beds here described. Professor Fairchild places the Warren beach south of Lake Ontario at 880 feet, and his next important water level, Lake Dana, at about 700 feet, both far above the highest interglacial stratified sand or clay at Toronto.[1]

CONCLUSIONS

One who studies the complex set of glacial and interglacial beds of the Toronto region is strongly impressed with the length of time demanded for their production. There is no reason to suppose that the withdrawal of the Iowan ice and the drainage of the waters which it dammed were more rapid than the similar series of events following the latest ice sheet. When the Toronto beds began to be formed the water level in the Ontario valley was probably lower than now in Lake Ontario, and some erosion had already taken place in the Don valley and at other points. There had been time for the warm climate plants to return from exile in full force and for forest trees of a most varied kind, though mainly deciduous, to grow and fall on the banks of the rivers. The unios, too, had already migrated north from the Mississippi stronger in species than they are now. All this may imply as long a time after the Iowan ice sheet withdrew as has elapsed since the last ice sheet departed, before the lowest beds of the Toronto Formation were even begun.

Then came the raising of the rocky barrier at the eastern end of the Ontario basin to sixty feet above the present level, and a halt at that level while the upper sands became browned and cemented with limonite. The climate grew cooler and and then ninety-four feet of clay and fifty-five feet of stratified sand were laid down at Scarboro', the eastern barrier rising meantime to 152 feet above the present level.

Then there was a halt in the elevation toward the northeast and at length a reversal of the motion, the northeastern end of the basin being depressed until the great Scarboro' lake was drained to a level probably much lower than that of Ontario at

[1] Bull. Geol. Soc. Am., 1899, p. 31 and p. 56.

present, and river valleys were eroded through 150 or 250 feet of sand and clay and widened so as to have gentle slopes.

It will be observed that the damming of the interglacial waters is held to be due to epeirogenic changes and not to the presence of ice, since it is inconceivable that an ice dam should hold its place at the Thousand Islands during the ages of mild climate required for the growth of the luxuriant Don forests, largely composed of trees that now barely reach the southern edge of Canada.

It is not unfair to assume that the time after the Iowan ice retreated until the commencement of the Toronto Formation was as long as from the retreat of the Wisconsin ice to the present, a time variously estimated at from 7000 to 30,000 years. The raising of the northeastern barrier of the Scarboro' lake to a height at least 150 feet above that of Lake Ontario may also have required thousands of years, if the results of Dr. Gilbert's investigations as to the rate of tilting of the present lake basins furnish the standard. These two stages cover only the first half of the interglacial time, and probably an equal number of thousands of years were required for the depression of the outlet below that of Lake Ontario and the cutting of wide and deep valleys through the Toronto Formation.

To arrive at the total length of the interglacial period it is not extravagant to double or even triple the number of years since the last Ice age, giving estimates of from 14,000 to 60,000 years or more. It will of course be understood that the length of time since Niagara began to cut its gorge can be estimated only vaguely and that the guess at the length of the interglacial period given here is still less certain.

How long a time the later series of bowlder clays and interstratified materials, more than 200 feet thick at Scarboro', required in their formation one can hardly even guess; but one of the glacial retreats amounted probably to more than 50 miles and may alone have demanded centuries of recession and advance.

The time element in the series of events described has been

somewhat strongly insisted on in this paper, since many geologists who have worked only in regions where the Pleistocene deposits are relatively simple in structure and not of great thickness are apt to underrate the importance of interglacial periods, looking on them as short episodes of retreat and advance in the history of a single Ice age. The evidence adduced here points to completely distinct Ice ages, separated by thousands of years of mild climate. It is not improbable that the present time is merely another interglacial period.

An interesting result of the action of rivers and ice is found in the change of relief in the region since the Iowan ice departed. The valley of the Laurentian river, then probably a hundred feet or more below the present level of Lake Ontario, is now replaced by Scarboro' Heights rising 350 feet above the lake and presenting the highest cliffs on its whole shore.

A summary of the best marked stages in the Pleistocene history of the region is given below, special reference being made to climates and water levels. The latter are of course not absolute levels but only relative, since the region as a whole probably underwent important elevations and depressions during Pleistocene times.

STAGES OF TORONTO PLEISTOCENE

1. Retreat of the Iowan ice sheet.
2. Interval of erosion with water probably lower than at present.
3. Don stage, warm climate trees and Mississippi unios, water dammed by differential elevation toward the northeast to 60 feet above the present lake.
4. Scarboro' peaty clays, cold temperate climate, with trees and mosses and 70 species of extinct beetles, formed as delta by Laurentian river in interglacial Scarboro' bay.
5. Scarboro' stratified sand with some trees and freshwater shells of cold temperate climate, delta completed, lake stands 152 feet above the present.
6. Water drawn off by lowering of outlet, subaerial erosion of previous beds, and cutting of river valleys more than 150 feet deep.
7. Advance of Wisconsin ice front raising the water to about 160 feet as shown by stratified interglacial clay, retreat for 50 miles and re-advance, followed by two later retreats and advances, the water finally rising 360 feet above the present lake.
8. Final retreat of ice sheet, followed by water levels of lakes Warren and Iroquois and a brief entry of the Gulf of St. Lawrence into the Ontario basin, which, however remained fresh.

A. P. COLEMAN.